Mine Ground Disaster Monitoring Based on Geosensor Networks

http://dx.doi.org/10.3991/ijoe.v11i1.4347

Jianmin Wang[1*], Yongzhan Zhang[2]
[1] Taiyuan University of Technology, Taiyuan, China
[2] Shanxi Province Institute of Surveying and Mapping, Taiyuan, China

Abstract—**Sensor network technology is one of the most promising technologies in the high technology field. Building integrated multi-sensor disaster monitoring system based on sensor network technology is the main direction of the intelligent disaster monitoring technique. The exploitation activities of the mineral resources may lead to geological disasters, so monitoring system needs to speed up the theory and technology innovations, i.e. disaster monitoring, forecasting, early warning and prevention. This paper expounds the concept connotation and key technologies of the geosensor network which contains constructing the unified mining space-time standards, sensor layout principles, and surface disaster monitoring technologies. In addition, the methods of data publication and service in sensor network based on sensor observation service (SOS) are also discussed. It also designs the integral framework of ground disaster monitoring system with SOS. Utilizing the geosensor networks in the ground disaster monitoring system to realize real-time access, cooperative observation, dynamic monitoring, analyzing and predicting the monitoring data will enhance disaster prevention and mitigation capabilities of the monitoring system.**

Index Terms—**Geosensor networks, Disaster monitoring, Sensor observation service, Smart mine**

I. INTRODUCTION

The exploitation of resources easily breaks the stress balance of underground rock, and easily lead to the loss of groundwater resources, and then it causes some disasters, such as surface subsidence, landslide, collapse, debris flow, ground crack and ground subsidence. In order to prevent mine geological disasters, make use of the land resources of mining areas and to protect the ecological environment of mining area, we need to monitor the stability of the damaged mining area. The traditional monitoring methods have not provided adequate security for modern mines. Owing to the sensor technology standardization and gradual improvement and development of the spatial information processing theory, building integrated multi-sensor disaster monitoring system based on sensor network technology is the main direction of the intelligent disaster monitoring technique.

Sensor network technology is one of the most promising technologies in the high technology field. The sensor network becomes an international research hotspot. So-called geosensor networks are specialized applications of various sensors technology in geographic space that detect, monitor, and track environmental phenomena and processes.

In geoscience, NASA proposed Sensor Web concept in 2001[1]: One network system is deployed to monitor and detect new environment. The system includes distributed sensors which can communicate with each other, and it focuses on software infrastructure, launches a multi-scale sensor network, heterogeneous sensor information model, sensor information service middleware and research of typical applications.

Geosensor is used more and more widely in the field of earth science in recent years. The geosensor network is named by its application in Geo-science and Environmental Science, and it is the embodiment and application of the latest domestic networking in the field of geoscience[2]. Chinese academicians made better technology of acquiring information automatically, and made a summarized discourse on the earth observation network of space earth integration[3].

There are more and more geosensor networks which are put into application, for example, research groups from Harvard, University of New Hampshire and North Carolina have collaborated for several sensor network deployments in the remote, inaccessible area at the active volcano Reventador in Ecuador in 2005–2008 [4–6]. The Chinese Academy of Sciences (CAS) Shanghai Institute of Microsystem cooperated with the CAS Chengdu Institute of Mountain, developed the technology of "the debris flow monitoring and early warning test system based on sensor network", which can collect, analyze and record various data before, during and after the occurrence of debris flow, and can provide accurate and timely information for forecasting and early warning of debris flow. In addition, the project team in the Beijing Normal University developed the "extreme environmental observation platform for wireless sensor networks". This program, which can be regarded as a typical case in sensor applications, is installed successfully in the Antarctic. Hehai University XGIS research team is committed to using multi-sensor network to monitor seawater change. There are a large number of cases which study the geosensor networks worldwide, such as the application on ground disaster and environmental monitoring with geosensor[5,6], and the network service system ion distributed sensor network data created by research group from Chen Nengcheng and Professor Di Liping from the George Mason University.

This paper pays core attention on the ground disasters caused by exploitation of mineral resources, such as mine goaf collapse, surface subsidence, mining field slope instability, landslides, rock avalanches and other geological disasters, and gives a comprehensive view on the key technologies of the ground surface monitoring system, which integrate multi-geosensor system.

II. KEY TECHNOLOGY OF GROUND DISASTER MONITORING

In this section, the technology, especially with regard to ground disaster monitoring, is reviewed in more details.

A. *Multi-source geosensor networks*

Due to the specialization and complexity of the mineral resources exploitation, and the complication and diversification of the ground disaster monitoring, it is necessary to set up a multi-source geosensor network system to achieve continuous, real-time auto-monitoring.

Geosensor network for disaster monitoring is a sensor network system which is established through sensors and database management software by Geodesic type sensors and geodesic auxiliary sensors, such as GPS, measurement robots, tilt sensors, displacement sensors, temperature and pressure sensors, panoramic cameras, CCD cameras, video sensors, RFID sensors, Terrestrial 3D laser scanners, and the foundation SARs, as well as computer networks and wireless communication technology[7].

Due to the complexity of mineral resources exploitation environment, the construction of sensor network needs to consider the several following principles:

1. Optimizing the layout of network, make full play to the monitoring efficiency of each sensor, for example, monitoring equipment shall be arranged on the characteristic points of the ground.
2. Sensor networks should have great scalability. If the monitor area is extended, new sensors can be added at any time;
3. Sensors can be interacted with each other, such as GPS, measurement robot, as well as temperature and pressure coordination;
4. The data communication should be stable to ensure a real-time dynamic monitoring;
5. The features of the monitoring data are time-series data, large data amount, diverse data formats, complex storage structure, permanent data storage and rapid data update.

B. *Monitoring reference of temporal-space*

Ground disaster monitoring is based on the geosensor; with different types of sensor, various data will be obtained. Geosensor data is a time-series observational data, but some sensors need no specific space location, for instance, pressure sensors, temperature sensors. In order to centrally manage sensor data and sensor data co-processing , it is a necessity to set up a unified and high-precision space reference. It is vital for high-precision deformation monitoring to choose reference rationally, as the reference is the important guarantee for safe production. And all management and processing of monitoring data should be carried out with the framework of the reference.

The traditional local fixed reference cannot meet the need of large-scale modern mining, therefore, the reference requires high accuracy as well as dynamic update and automatic maintenance. Constructions of high-precision space mapping reference is the only choice of development of "the smart mine"

In the past twenty years, GNSS made great contributions to space geodetic work as a positioning reference tool, and also, it will make further efforts to improve the geodetic observations. Bringing space monitoring reference into GNSS reference frameworks is undoubtedly a reasonable choice. With the wide use of continuous operation reference station(CORS) in GNSS, it is practical to build up space survey monitoring reference via technology and service from CORS. Fig.1 shows the technology process of regional CORS.

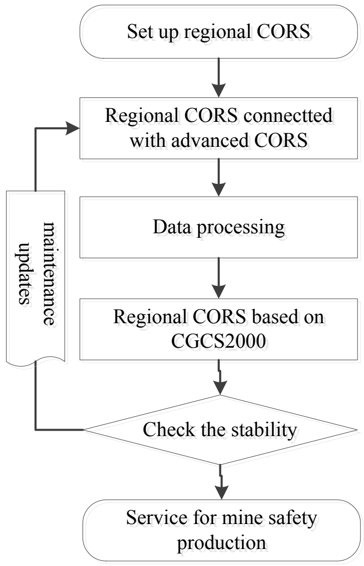

Figure 1. The technology process of CORS

C. *Detection techniques of dynamic changes on mining area*

Changes in mine waste rock deposits, land categories after mining area reclamation and vegetation distribution can be considered as ground target change detection problem. With the development of sensor technology, high-resolution, multi-temporal, hyperspectral, multi-source data dynamic change detections become a hot issue around the world. The existing research methods can be summarized into two categories: the first is to detect changes after registration, and the second is to detect synchronizes with registration. However, the basic ideas of change detections, both the former and the latter, are based on pixel algebra and transform or feature extraction[8].

Long-term exploitation of mineral resources can sometimes break the balance of original water resources system, lead to the overburden slowly sinking and moving, and the deformation caused by exploitation cannot be detectable for a short time, but, in the long run, it is objective existence. The deformation affects large scopes and areas. Sometimes the whole mine area, sometimes even more than that, so the devastation cannot be neglected. The feature of such deformation is slow processing, affecting a wide scope, it has accumulation effect in the long term and is continuous from the space aspect. Some scholars use InSar image to monitor the whole mining area land subsidence[9], and achieved good results, but there is still some disadvantages, for example, its monitoring period is too long to achieve a fixed-point continuous monitoring toward deformation areas, and the monitoring results in small range are not obvious. Also, we can use 3-D laser scanning technology to monitor the surface subsidence. With the grid scanning mode, we can measure surface point with a high-precision, high-density, high-speed and non-prism way, its characteristics of high-temporal-resolution, high-spatial-resolution and uniform measurement accuracy will exhibit detail and integral deformation clearly. However, its shortcoming is that it cannot achieve tie points' variation.

The underground mining will destroy the overburden stress balance, which can trigger surface subsidence and slope displacement. But, this sort of deformation has characteristics of large deformation, fast speed, and great damage. Combine measuring robot with global navigation satellite system(GNSS), and apply them to set up a full-time, automatic deformation monitoring system, which is available for monitoring underground mining and slope displacement. Put the detecting prism into monitoring area, and laying the measuring robot at the monitoring reference point, the coordinates of reference points are regular updated by GNSS. The greatest advantage of this technology is that it can monitor corresponding points, and the variation based on multi-period monitoring results will be more persuasive. Automatic monitoring technology has features of real-time monitoring, fast response speed, high precision, etc.

Research groups from Taiyuan University of Technology have studied automation system based on geosensor networks for mine slope deformation monitoring. The system is mainly composed of surveying robot, GNSS, video and meteorological sensors.

In recent years, several domestic and overseas scientific research institutions carried out researches on ground-based SAR, and its non-contact measurement methods can be obtained within a safe distance from the monitored deformation data of the danger zone. Meanwhile, the information collected is territorial deformation data with large area. It is better to predict disasters than deformation information on a single point [10].

In the application of ground-based SAR, various projects have been developed on landslide monitoring, avalanche mountain recognition, glacier area monitoring. And in China, ground-based SAR has also been used in deformation monitoring of open-pit coalmine. It is a breakthrough in domestic coal mine micro slope deformation monitoring field. Fig .2 is a slope monitoring which uses ground-based SAR technique in Pingshuo Mine. Its characteristics are as follows: high spatial resolution, long-term continuous monitoring, flexible installation, high monitoring precision. All these features can greatly reduce the cost of manpower and improve the efficiency of the monitoring work. Fig.3 is the interface for real-time monitoring and analysis system , which can reflect the deformation parameters such as deformation displacement, deformation speed, speed countdowns, etc.

D. *Temporal-space registration of monitoring data and disaster forecast*

Multi-source sensors are sensors of same or different types which are distributed in different platforms. Due to its different locations, coordinate systems, and sampling frequency which are chosen before the data processing, different kinds of sensors will obtain monitoring target data of tremendous variations, even though the monitoring is towards the same target. So, when facing the data processing of which the data is obtained from multi-source sensors, it is an essential way to unify all data to one temporal-spatial reference.

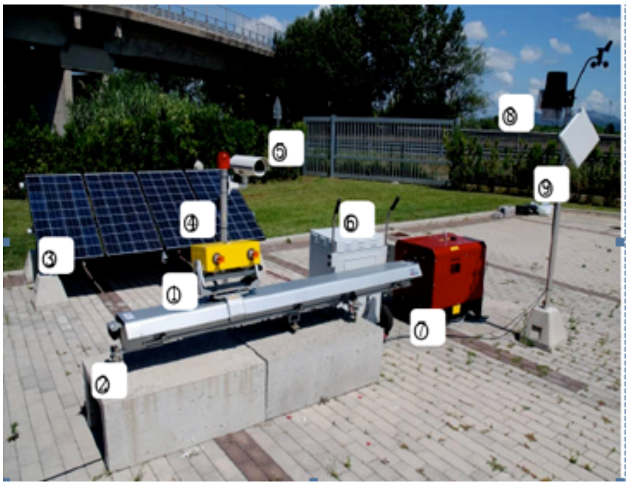

Figure 2. Ground-based SAR

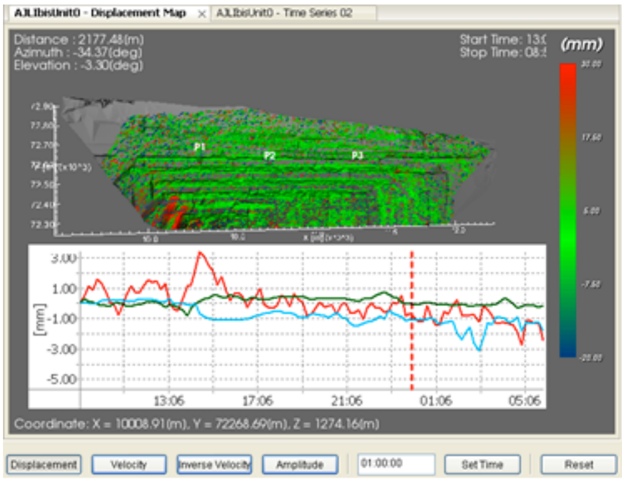

Figure 3. Data processing

The preceding paragraphs have discussed the establishment of temporal-space reference. And in the multi-sensor data processing system, the sensor data fusion processing must be of the same time [11] , so that the correct state can be calculated, and the time calibration can be carried out. A coherent time system is a prerequisite to the time calibration. As we all know, GPS devices use GPS time, while measuring robots use Beijing time, so different types of time should be unified to a coherent time system, such as Beijing time or Internet time. Time calibration refers to the application of interpolation and extrapolation, fitting algorithm to deal with each sensor observation sequence. It can make sensors to provide the data of the same target at the same time. And there are a lot of solutions to carry out time calibration, such as the interpolation extrapolation, Taylor expansion amendment.

The fact that integration of multi-sensors can achieve all-round and multi-angle detection data is the prerequisite of disaster monitoring. In addition to this, when facing the multi-source, multi-scale and different-structure data, a scientific and reasonable data analysis theory and calculation analysis can help to find the deformation feature and law of deformable body, to predict disaster time, to take measures to prevent the occurrence of disaster and to avoid the adverse consequences of disasters. Consequently, it is the fundamental function of deformation monitoring to predict the deformable feature and trend accurately.

Deformation prediction is a multi-disciplinary task that requires taking into account the impact of the surrounding environment, such as the slope (landslide) movement, it is affected by the mining, exploitation blasting, surrounding motor vehicles, rain soaked and many other effects. And also, it has close relationship with the factors on causes of deformation, geological structure, external force nonlinearity and uncertainty. In general, predicting models can be made by analyzing functional relationship between physical variations and deformation quantities, and the condition of deformable bodies can be calculated in future via predicting models. The model can be evaluated by the comparison between the predicted and measured values, but owing to the diversity and complexity of the factor which causes the deformation, it is impossible to parameterize all the influencing factors. Setting up a proper deterministic model is always a harsh problem[12] because an unsuitable choice of mode parameters will lead to a low precise forecasting.

In recent years, some scholars use mathematical model to approach, simulate, and reveal the dynamic characteristics and regular pattern of deformation. Below are some typical models: different sorts of regression analysis models like multiple linear regression, stepwise regression analysis and principal component regression analysis[13]; time series method[14]; Kalman filter method[15]; Artificial neural network model[16,17]; Wavelet transform model[18], Image Fusion Algorithm[19],etc. These predictive models each have their own appropriate conditions as well as limitations, because the assumed condition and modeling mechanism between each predicting model are not the same.

III. SYSTEM PUBLICATION AND SERVICE OF GEOSENSOR NETWORKS DATA

With the smart city and networking development plan being put forward and the development of sensor network industry, there are more and more sensors which can be used to collect a variety of data and real-time observation state data. How to share and make full use of the real-time data obtained by sensors becomes one of the issues for researches on real-time data sharing in the sensor network fields[20].

Since 2004, Open Geo-Spatial Consortium (Open Geospatial Consortium, OGC) and the International Organization for Standardization Geographic Information Working Group (ISO/TC211) have been committed to promoting Sensor Web. The standard and protocols of Sensor Web development have been released. Currently OGC has set seven sensor network standards, including four implementations of information services and three information models, which form the SWE[21] (Sensor Web Enablement, SWE). And among them, SOS is one of OGC sensor criterion launched in the 2007, and it provides a standard mode to obtain information from remote sense, field monitoring, stationary or mobile sensor system. SOS is the most important part in sensor network service system. It can provide standard information mode for observations and measurements via standard interface.

Releasing real-time data from geosensor networks can be committed for more engineers and researches to participate in disaster monitoring research. This research can save cost and improve efficiency, and the published results from monitoring researches can bring more personnel to carry out a real "mass prediction and disaster prevention".

Prototype systems of multi-sensor disaster monitoring system use browser/server (B/S) and desktop/server (C/S) which is designed from J2EE frameworks. The system consists of data collection and transmission layer, data management layer and information dissemination and service layer, and the structures of prototype systems are shown in Fig.4.

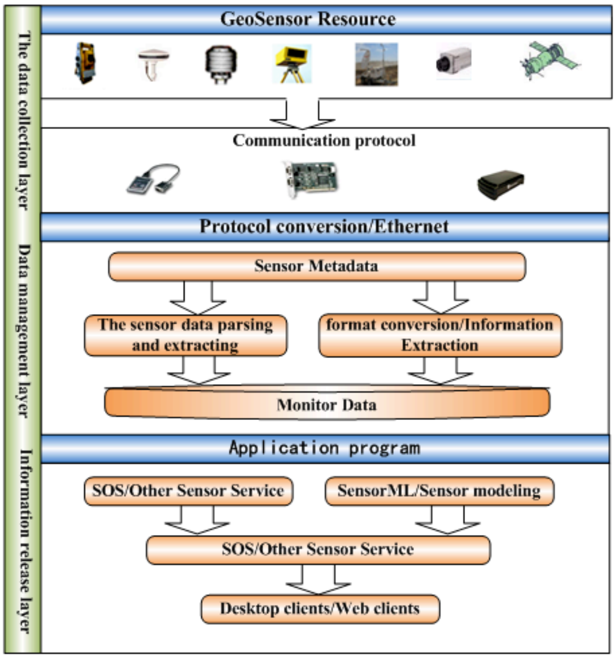

Figure 4. Multi sensor integration system framework for the ground disaster monitoring

Data collection and transmission layer, a geosensor networks system which is composed of multi-source geosensor device, and its functions are real-time access, dynamic observation. The establishment of communications systems and local area network system can ensure the stability of data transmission and the continuity of monitoring.

Data management layer, an established sensor information mode which is based on the sensor metadata and using SensorML to describe sensors, can give the sensor space and temporal characteristics, operate professional analysis and information extraction, unify space and temporal data, and make the observed sensor network data access to the unified management and monitoring database in real time.

Information dissemination and service layer, gets the real-time monitoring data from the surface sensor network, uses single data analysis method, multi-source data analysis and comprehensive analysis of the calculation method, and shows the results in the space visually. Data processing analysis is run by the C/S mode, namely, desktop client. In addition, publishing the analysis of the observational data and calculated results to the Web which is run by the B/S mode, is realized by the browser client.

IV. CONCLUSION AND OUTLOOK

In the 21st century, there will be opportunities as well as challenges for mining operators as the construction of smart city would be extended inevitably to the mining industry. And with the wide use of sensor technology in safe production of mineral resources, such as gas monitoring, groundwater monitoring, mining pressure monitoring, it is out-of-date that most mines in China are using sensors of single type in the surface disaster monitoring and its data processing is relatively simple, The traditional monitoring method is unable to provide adequate security for the modern mine production. As the sensor technology has been gradually standardized, and spatial information processing theory has been continuously improved and developed, construction of multi-source geological sensor network disaster monitoring system is bound to be an important component in the construction of " the smart mine".

The establishment of multi-source sensor network system is to achieve various types of sensors to obtain spatial information interconnection and interoperability. And it will also make multi-source heterogeneous information real-time access and dynamic load come true. Study and formulation on unified space-time system under a variety of types of spatial information access and load specification, researches and development on multi-source sensor information access, load, fusion, updating the components of the tool and spatio-temporal data integration analysis as well as decision-making simulation technology platform, are the development trend of geosensor networks.

This paper gives an overview of the current technology to build geosensor networks system used in disaster monitoring. Among those technologies, establishment of mine temporal reference is the basic factor, deployment of sensor network is the crucial factor, data analysis and processing are the key factors, and disaster prediction is the target.

REFERENCES

[1] Z. Zhang and N. Chen, "Design and implementation of sensor observation server," *Journal of Geomatics*,2010,vol. 35,pp. 49-53

[2] X. Zhang, "Industry data model development of the sensor network," http://blog.sina.com.cn/s/blog_643115fc0100osjl.html, July 2013

[3] D.Li, "On space air ground integrated earth observation network, "*Journal of Geo-Information Science*, vol.14, pp. 419-424, 2012. http://dx.doi.org/10.3724/SP.J.1047.2012.00419

[4] G. Werner-Allen, K. Lorincz, M. Ruiz, O. Marcillo, J. Johnson, J.Lees, M. Welsh ,"Deploying a wireless sensor network on an active volcano, "*IEEE Internet Computing*, vol.10,no.2, pp. 18–25,2006. http://dx.doi.org/10.1109/MIC.2006.26

[5] L. Peci, M. Berrocoso, R. Paez, "IESID: Automatic system for monitoring ground deformation on the Deception Island volcano (Antarctica)," *Computers and Geosciences*, vol.48, pp. 126-133,2012. http://dx.doi.org/10.1016/j.cageo.2012.05.004

[6] N. Silvia, "A Survey of Geosensor Networks: Advances in Dynamic Environmental Monitoring,"*Sensors*,vol.9,no.7 , pp. 5664-5678,2009. http://dx.doi.org/10.3390/s90705664

[7] J.Zhang, "The Geosensor Networks for Precise Monitoring of Mine Ground Disaster,"*Journal of Geo-Information Science*,vol.14 , pp. 681-685,2012.

[8] Z.Shi, K.Qin, J.Chen, "Key theories and technologies on reliable dynamic monitoring for national geographical state," *Chinese Science Bulletin*, vol.57, pp. 2239-2248, 2012. http://dx.doi.org/10.1360/972011-2467

[9] X. Zhang, D. Ge, L.Wu, "Study on monitoring land subsidence in mining city based on coherent target small-baseline InSAR," *Journal of China Coal Society*, vol.37, pp. 1607-1611,2012.

[10] S.Qu, Y.Wang, W.Tan, "Deformation Detection Error Analysis and Experiment Using Ground Based SAR," *Journal of Electronics & Information Technology*, vol.30, pp. 1-6,2011. http://dx.doi.org/10.3724/SP.J.1146.2010.00250

[11] B. Zhou, Y. Lu, "Research on the data preprocessing technique in multi-sensor data fusion system,"*Infrared and Laser Engineering*, vol.36, pp. 246-249,2007.

[12] J.Xiao, J.Zhang, "Analysis and application of automatic deformation monitoring data for buildings and structures of mining area," *Transactions of Nonferrous Metals Society of China*, vol.3, pp.516-522, 2011. http://dx.doi.org/10.1016/S1003-6326(12)61634-3

[13] J.Zhang, L.Song, J.Zhang,"The Application of Multiple Regression Analysis Models in Deformation Monitoring," *Journal of Henan Institute of Engineering*, vol.21,pp. 22-25,2009.

[14] M. Sui, J. Chen, Y. Shi,"Integration of time series analysis and spectrum analysis and its application in deformation data processing and forecasting," *Geotechnical Investigation & Surveying*,no.11, pp. 376-80,2011.

[15] B. Sonja, F. Karl, W. Peter, "Evaluation of linear Kalman filter processing geodetic kinematic measurements, "*Measurent*, vol.41,pp. 561-578,2008.

[16] J.Sheng and M.Xiong, "Slope stability forecasting method based on Grey and BP Neutral Network combined model," *Nonferrous Metals(Mining Section)*, vol.64,no.4, pp. 71-75, 2012.

[17] Y. Huang and Y.Xu, "Slope deformation forecast based on wavelet neural network," *Engineering of Surveying and Mapping*,vol.21,no.2 ,pp.61-64,2012.

[18] C.Ren, L.Sha, X.Lu, "An adaptive wavelet thresholding denoising for deformation analysis,"*Geomatics and Information Science of Wuhan University*,vol.37,no.7 ,pp. 873-875, 2012.

[19] F.Zu and H.Zhu, "A Multi-resolution Image Fusion Algorithm Based on Multi-factor Weights," *Journal of Digital Information Management*,vol.12.no.5,pp. 303-310,2014.

[20] L. Miao and X.Ma, "Publishing the observation geoscience data acquired by integrated geosensors to support real-time sharing," *Microcomputer Information*,vol.27,no.11 , pp. 1-4, 2012.

[21] A. Bröring, J.Echterhoff, S. Jirka, T. Everding, I.Simonis, et al., "New Generation Sensor Web Enablement," *Sensors*, vol.11,pp. 2652-2699,2011. http://dx.doi.org/10.3390/s110302652

AUTHORS

Jianmin Wang (Corresponding author) is a lecturer in College of Mining Technology , Taiyuan University of Technology, Taiyuan, 030024, China (email: 8844.4321@163.com)

Yongzhan Zhang is with Shanxi Province Institute of Surveying and Mapping, Taiyuan, 03002, China (email: 452393084@qq.com)

The work described in this paper was substantially supported by the foundation of Shanxi Province (grant no. 2013041060-02). Submitted 19 December 2014. Published as resubmitted by the authors 25 January 2015.